Advanced bridge hydraulics can be observed in ancient structures such as the Némes aqueduct in France, shown here. This is a view looking downstream at Pont-du-Gard across the Gardon River.

Knowledge of the ancients

by Hubert Chanson

While some scholars suggest Roman engineers did not know the basic principle of conservation of mass, Roman aqueducts clearly demonstrate a high level of hydraulic engineering expertise.

The successful design and operation of these magnificent systems are massive achievements even by modern standards. The development of regulation basins, culverts and energy dissipators, including dropshaft cascades and stepped chutes, was far from obvious, even for today's engineers. The complexity of basic fluid mechanics is linked with governing equations characterised by nonlinearity. The leading Roman hydraulic engineers involved with the major aqueducts in Gaul and North Africa understood the fluid mechanics principles of continuity and momentum.

The Roman aqueducts are a superb example of hydraulic engineering. They were some successful civil engineering designs encompassing hydrology, fluid dynamics, structural engineering, soil mechanics, surveying and water management. Such projects form the backbone of our civil engineering profession, and the writer believes that many university students, professionals and academics could learn a lot from the success stories that are the Roman aqueducts.

What is an aqueduct?

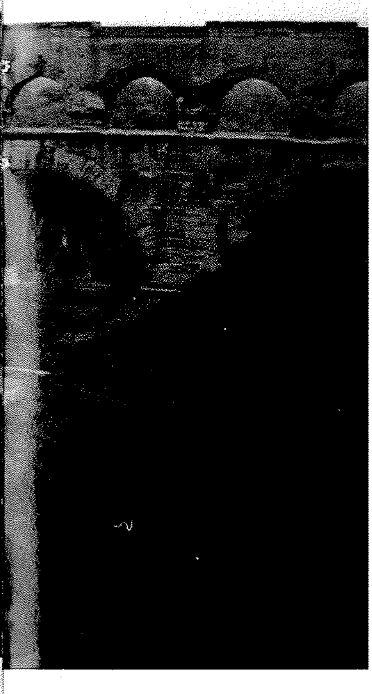
The Roman aqueducts were long subterranean conduits following topographic contour lines. Some included major engineering structures like arcades, bridges and inverted siphons. The majority of the water system was built at or just below the natural ground level.

The water was flowing has an open channel flow and the water depths were typically between less than 0.05m and 1m.

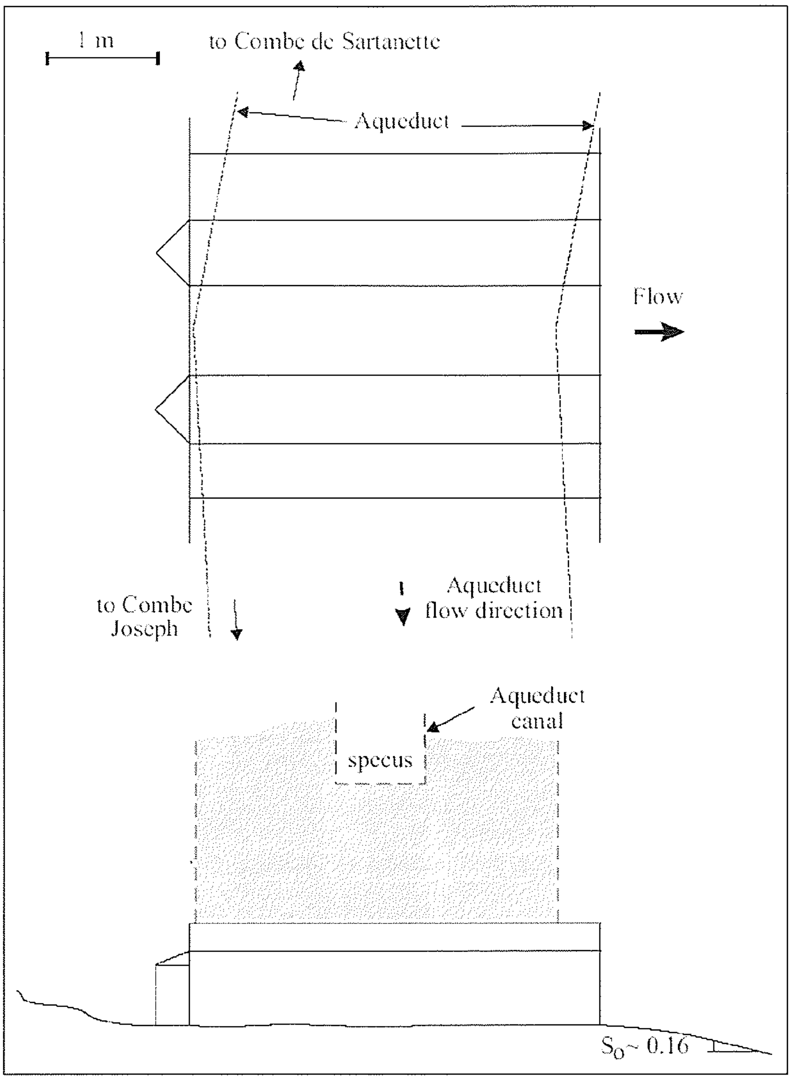
The conduit was covered by a circular arch roof to minimise the influx of impurities and ensure the water quality.

The aqueducts served towns and were always built after the town establishment, and they did not constitute the original drinking water supply.

The construction of an aqueduct was a huge task, sometimes



performed by the army under the guidance of military hydraulic engineers. The first major aqueducts were built to supply waters to the city of Rome. The longest system was the 132km-long Carthage aqueduct regarded as one of the marvels of the world by the Muslim poet El Kairouani.



A dimensioned sketch of the Vallon No. 6 multi-cell culvert beneath the Némes aqueduct in France, demonstrating experience and knowledge in dealing with stormwater runoff and its conveyance beneath a major structure.

Who were the engineers behind it all?

The hydraulic engineering expertise in Roman times was restricted to a handful of engineers. The construction of an aqueduct involved hundreds of workers and could take between three to 15 years. Although there is no written proof that the Romans knew the basic concepts of continuity and energy as used in modern hydraulics, their engineers understood the principle of continuity, probably those of momentum and energy. The aqueduct engineers designed reliable energy dissipation structures and storm water floodways which were used for centuries.

Although little is known on the hydraulic engineering of Roman aqueducts and their design engineers, a re-analysis of the aqueduct hydrology and hydraulic engineering reveals new evidence.

Hydrological considerations

Although there is little information on the ancient climate and ancient flow rates, during the 20th century, it is believed discharge variability was likely to occur in Roman times, and these must have affected the water distribution.

Reservoirs and cisterns had to be used to regulate the water distribution in town. In a recent analysis of the operation of two aqueducts, it was demonstrated that the regulation of the flow was a necessity a) to prevent overflows and unsatisfactory aqueduct operations during wet seasons, b) to provide optimum flow conditions (minimum energy losses and maximum flow rates) during low-flow seasons, c) to regulate the outflow and d) for maintenance.

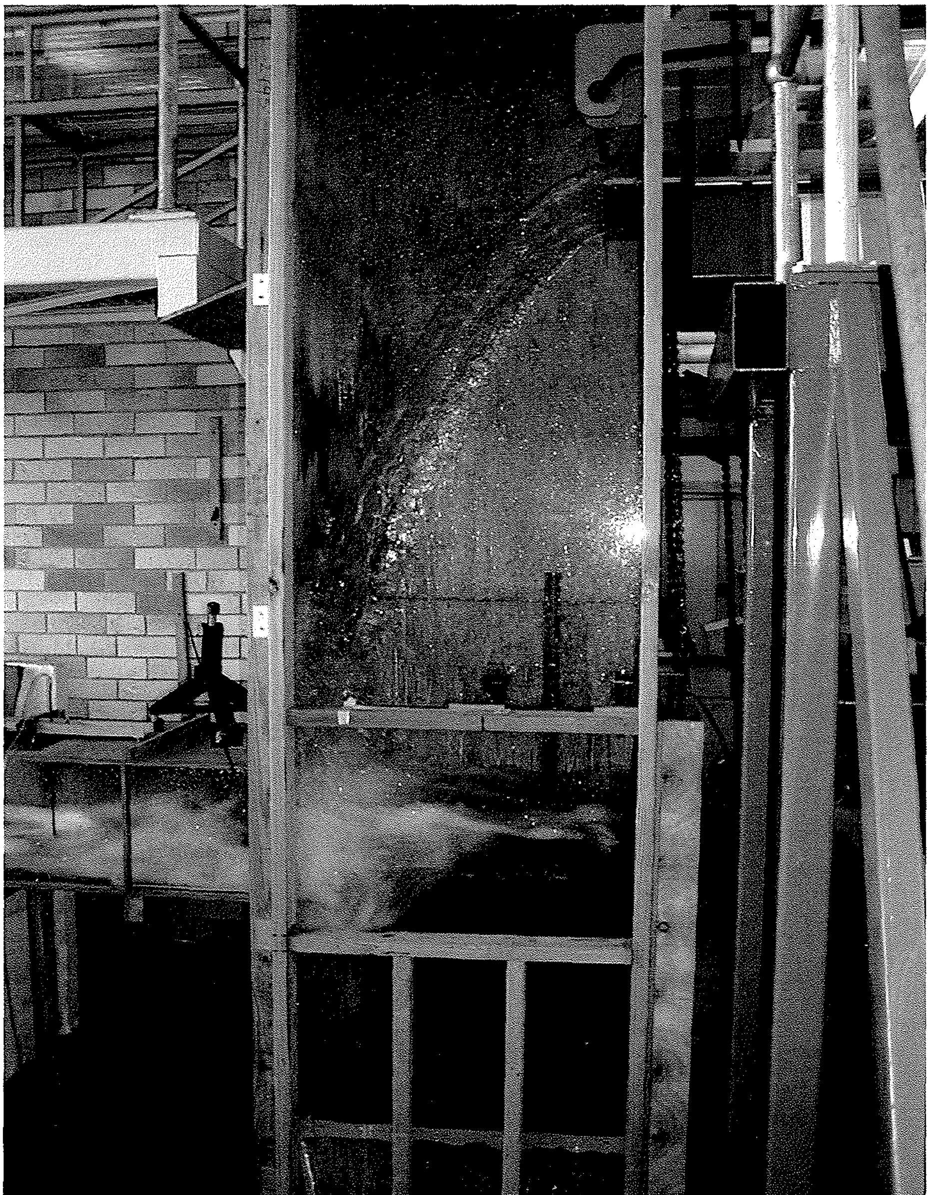
A basic regulation method On-Off was required for regular maintenance works, including cleaning and repairs. One such regulation technique was the dynamic regulation, commonly used today in open channel systems. Such a technique regularised the flow rate to satisfy the users' needs during day times and to store water in the aqueduct during night times.

I argue that the Romans used such a dynamic regulation technique, on a daily and possibly weekly basis, to store water at night and during low-demand periods. The storage capacity of an aqueduct could be significant – about 20,000m^3 and 50,000m^3 at Gorze and Némes. This could provide one to three weeks of water supply depending upon the population and the level of water restrictions.

An unusual stormwater system

The knowledge of the catchment hydrology was essential to select a suitable water supply as well as to design the stormwater drainage systems protecting the stability and integrity of the aqueduct system.

The Romans used several culvert designs beneath their roads, the most common designs being the arched culvert and the rectangular, box culvert. But few culverts were built beneath aqueducts and this structure showed unusual features such as a)



The hydraulics of Roman dropshafts were recently tested at the University of Queensland, suggesting their design was complex by modern standards. Shown here is a full-scale model of a rectangular dropshaft installed on the Yzeron aqueduct at Recret.

a box culvert of large dimensions, b) a multi-cell structure, and c) a modern and sound design from a hydraulic perspective.

While many studies highlighted the hydraulic expertise of the Romans for small to medium discharges, the hydraulic design of the Vallon No. 6 multi-cell culvert beneath the Némes aqueduct in France demonstrates some hydraulic experience and knowledge in dealing with large stormwater runoff and its conveyance beneath a major structure.

Energy dissipation

The existence of steep inverts in aqueducts implies the flow became supercritical and some hydraulic devices were required to dissipate the kinetic energy of the flow along the steep section and at its downstream end when the channel connected to a flat section.

The energy dissipation system was essential to ensure normal downstream flow operation and to prevent scour and damage to the structure. Three types of structures were used: a) a smooth steep chute followed by some hydraulic jump dissipator, b) a stepped chute, and c) some dropshaft or dropshaft cascade.

The hydraulics of Roman dropshafts was recently tested at the University of Queensland. The results of these investigations highlighted that the operations of both single dropshaft and dropshaft cascade designs were complex by modern standards. Today, the design of dropshaft is restricted to a handful of experienced engineers and usually verified by extensive physical modelling.

What can we learn from them?

The design of an aqueduct was a difficult task. Several aqueducts included hydraulic systems (regulation basins, dropshaft, stepped chutes, culvert) that required advanced hydraulic engineering knowledge. In particular, the hydraulic design of stepped chutes, dropshafts and multi-cell culverts is not today a simple job. This is a highly specialised task and the advice of an experienced engineer is required.

Further the construction of an aqueduct required some solid hydrological expertise; not only to select the suitable spring(s) but also to ensure a safe operation of the aqueduct system during rain storms. The latter involved the design of overflows in the in-stream regulation systems, and also the construction of culverts and bridges at stream and gulley crossings.

Remains of advanced bridge hydraulics include the Pont-du-Gard, Pont de Bordnégre on the Némes aqueduct between Uzés and Pont du Gard, and the Gorze aqueduct-bridge above the Moselle river near Ars-sur-Moselle for example. Other examples include several crossing along the Mons aqueduct between Mons and Fréjus.

Examples of bridge hydraulic expertise included the Pont de Bornégre and the Gorze aqueduct bridge. The former was composed of three arches with two centre piers equipped with upstream cut waters. The latter was a 1100m-long, 32m-high bridge across the Moselle River. This river is affected by large floods. ●

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